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NOVA CODE SIMULATION OF A 155-mm HOWITZER: AN UPDATE

Albert W. Horst
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October 1979

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

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The NOVA two-phase flow interior ballistic code was employed to simulate ignition, flamespreading, and pressurization in a 155-mm Howitzer. For these calculations, all input data were independently determined, and comparison was made between predicted results and experimental data. Good agreement between theory and experiment was shown to exist for overall pressurization profiles and, in one case, for pressure waves themselves. However, experienced ignition delays were grossly underpredicted, suggesting several specific limitations to the model.

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I. INTRODUCTION

A number of recent publications[1-5] have described application of the NOVA one-dimensional, two-phase flow interior ballistic code[6-9] to various gun/propelling charge configurations. In general, while reasonable agreement between predicted pressure-wave characteristics and experimental data (particularly as described by the pressure-difference profile depicted in Figure 1) has been shown for cased-ammunition guns, a similar level of agreement for bagged charges was not attained. It is tempting to attribute this disparity to the more obvious non-one-dimensionality of bagged-charge configurations (see Figure 2) which allow potentially significant radial velocities to develop in both gas and solid phases early in the ballistic cycle. Indeed, a two-dimensional, axisymmetric version of the NOVA code is currently under development, at least in part, in response to this lack of success. Nevertheless, before dismissing the one-dimensional NOVA code from treatment of problems associated with bagged charges, the following exercise was undertaken, providing a comparison between NOVA simulations and experimental data for performance of a 155-mm bagged charge at two extreme loading conditions.

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[1] *C. W. Nelson, "Some Simulations of a 155-mm Howitzer with the NOVAE Code," USA ARRADCOM, USA Ballistic Research Laboratories Interim Memorandum Report No. 451, Aberdeen Proving Ground, MD, November 1975. (No longer available.)*

[2] *C. W. Nelson, "NOVAE Code Simulation of a 155-mm Howitzer with a Chamber Length Charge," USA ARRADCOM, USA Ballistic Research Laboratory Interim Memorandum Report No. 468, Aberdeen Proving Ground, MD, January 1976. (No longer available.)*

[3] *A. W. Horst, T. C. Smith, and S. E. Mitchell, "Key Design Parameters in Controlling Gun Environment Pressure Wave Phenomena - Theory Versus Experiment," 13th JANNAF Combustion Meeting, CPIA Publication 281, December 1976.*

[4] *A. W. Horst and P. S. Gough, "Influence of Propellant Packaging on Performance of Navy Case Gun Ammunition," Journal of Ballistics, Vol. 1, No. 3, pp. 229-258, 1977.*

[5] *A. W. Horst, C. Nelson, and I. May, "Flame Spreading in Granular Propellant Beds: A Diagnostic Comparison of Theory to Experiment," AIAA Paper No. 77-856, July 1977, AIAA/SAE 13th Propulsion Conference.*

[6] *P. S. Gough, and F. J. Zwarts, "Theoretical Model for Ignition of Gun Propellant," SRC-R-67, Space Research Corporation, North Troy, VT, December 1972.*

[7] *P. S. Gough, "Fundamental Investigation of the Interior Ballistics of Guns," IHCR 74-1, Naval Ordnance Station, Indian Head, MD, July 1974.*

[8] *P. S. Gough, "Computer Modeling of Interior Ballistics," IHCR 75-3, Naval Ordnance Station, Indian Head, MD, October 1975.*

[9] *P. S. Gough, and F. J. Zwarts, "Some Fundamental Aspects of the Digital Simulation of Convective Burning in Porous Beds," AIAA Paper No. 77-855, AIAA/SAE 13th Propulsion Conference, July 1977.*

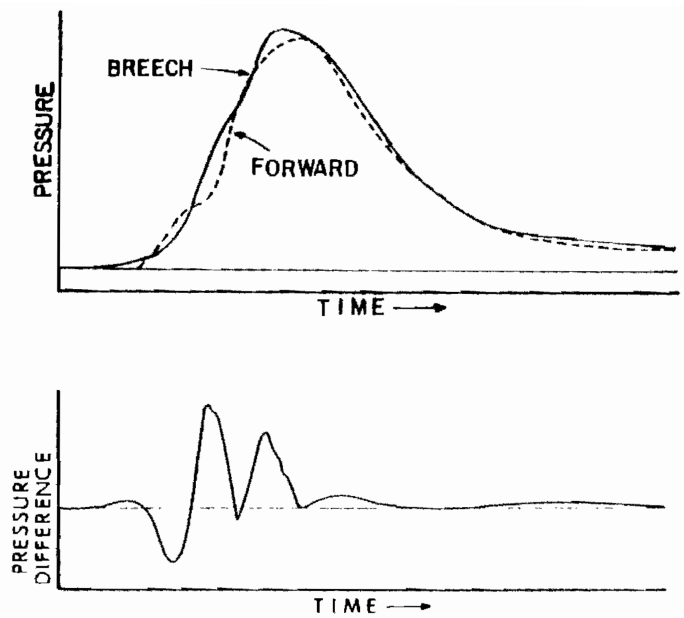

Figure 1. Breech and Forward Pressures vs. Time; Breech Minus Forward Pressure (Pressure Difference) vs. Time

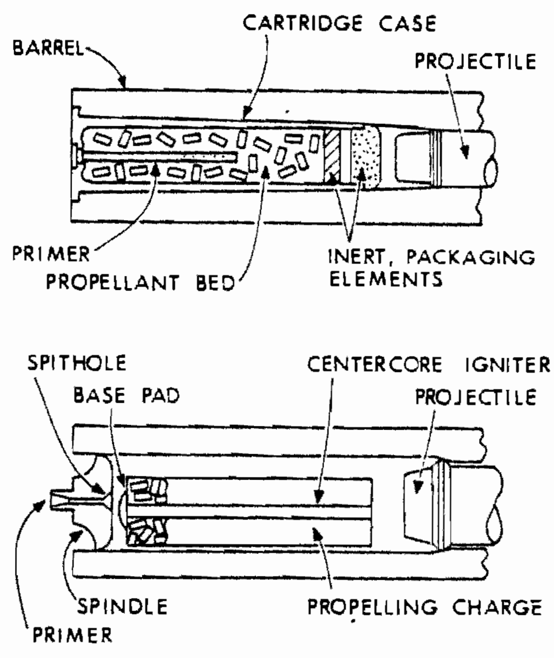

Figure 2. Typical Cased and Bagged Propelling Charges

II. CODE DESCRIPTION

Several versions of the NOVA code have been generated since its birth in 1972. Documentation on the most recent, and certainly most powerful, NOVA code is undergoing preparation by Paul Gough Associates and will be published as a Naval Ordnance Station, Indian Head (NOS/IH) Contract Report. A recent AIAA publication[9] provides an essentially accurate description of this code as used in the current study.

NOVA consists of a two-phase flow treatment of the gun interior ballistic cycle formulated under the assumption of quasi-one-dimensional flow. The balance equations describe the evolution of averages of flow properties accompanying changes in mass, momentum, and energy arising out of interactions associated with combustion, interphase drag, and heat transfer. Constitutive laws include a covolume equation of state for the gas and an incompressible solid phase. Compaction of an aggregate of grains, however, is allowed, with granular stresses in excess of ambient gas pressure being taken to be in accord with steady state measurements. Interphase drag is represented by reference to the empirical, steady state correlations of Ergun[10] and Andersson[11] for fixed and fluidized beds, respectively. Interphase heat transfer is described similarly according to Denton[12] or Gelperin-Einstein[13]. Functioning of the igniter is included by specifying a predetermined mass injection rate as a function of position and time. Flamespreading then follows from axial convection, with grain surface temperature being deduced from the heat transfer correlation and the unsteady, heat conduction equation, and ignition based on a surface temperature criterion. In addition, internal boundaries defined by discontinuities in porosity are treated explicitly, and the forward external boundary reflects the inertial and compactibility characteristics of any inert packaging elements present between the propellant bed and the base of the

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[10] *S. Ergun, "Fluid Flow Through Packed Columns," Chem. Eng. Progr., Vol. 48, pp. 89-95, 1952.*

[11] *K. E. B. Andersson, "Pressure Drop in Ideal Fluidization," Chem. Eng. Sci., Vol. 15, pp. 276-297, 1961.*

[12] *W. H. Denton, "General Discussion on Heat Transfer," Inst. Mech Eng. and AM. Soc. Mech Eng., London, 1951.*

[13] *N. I. Gelperin, and V. G. Einstein, "Heat Transfer in Fluidized Beds," Fluidization, edited by J. F. Davidson and D. Harrison, Academic Press, 1971.*

projectile. Solutions are obtained using an explicit finite difference scheme based on the method of MacCormack[14] for points in the interior and the method of characteristics at internal and external boundaries.

III. INPUT DATA

The system modeled was the U.S. Army 155-mm, M198 Howitzer firing the M483A1 Projectile with the M203E1 Propelling Charge (Zone 8). This charge is essentially the same as that depicted in Figure 3, with possible extreme loading configurations shown schematically in Figure 4. Since previously acquired experimental data had revealed significantly different levels of pressure waves accompanying the charge-spindle touch and maximum standoff conditions, both configurations were simulated.

A complete listing of input data is included as an Appendix. Many of the data are seen to be a result of direct measurements (e.g., configural dimensions), to reflect values taken from the literature (e.g., thermal conductivities), or to be of an administrative nature. However, much of the required input is not readily available. Propellant burning rate data are often considered to be "adjustable parameters", available to fine-tune agreement between theory and experiment. For this study, burning rates were based on recent closed bomb testing of M30A1 propellant performed at both the Naval Ordnance Station, Indian Head and the Ballistic Research Laboratory. Burning rate versus pressure data from half a dozen tests were lumped together, and exponential (aP^n) fits to the data were obtained in a piecewise-continuous manner to reflect an apparent slope break, as shown in Figure 5. Closed bomb data below 20 MPa were extremely irreproducible and were disregarded for this exercise. Input data describing igniter performance were based on experimental measurements obtained using a 155-mm ballistic simulator[15]. Propellant thermochemical data were calculated using the BLAKE Code[16], as amended in August, 1978. Finally, projectile engraving/bore resistance data were based on experimental data acquired at BRL using instrumented projectiles (see Figure 6)[17].

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[14] *R. W. MacCormack, "The Effects of Viscosity in Hypervelocity Impact Cratering," AIAA Paper No. 69-354, AIAA 7th Aerospace Science Meeting 1969.*

[15] *K. J. White, USA Ballistic Research Laboratory, Aberdeen Proving Ground, MD, Personal Communication, December 1977.*

[16] *E. Freedman, "A Brief Users Guide for the BLAKE Program," USA ARRADCOM, USA Ballistic Research Laboratory Interim Memorandum Report No. 249, Aberdeen Proving Ground, MD, July 1974. (No longer available.)*

[17] *E. V. Clarke, Jr., USA Ballistic Research Laboratory, Aberdeen Proving Ground, MD, Personal Communication, October 1978.*

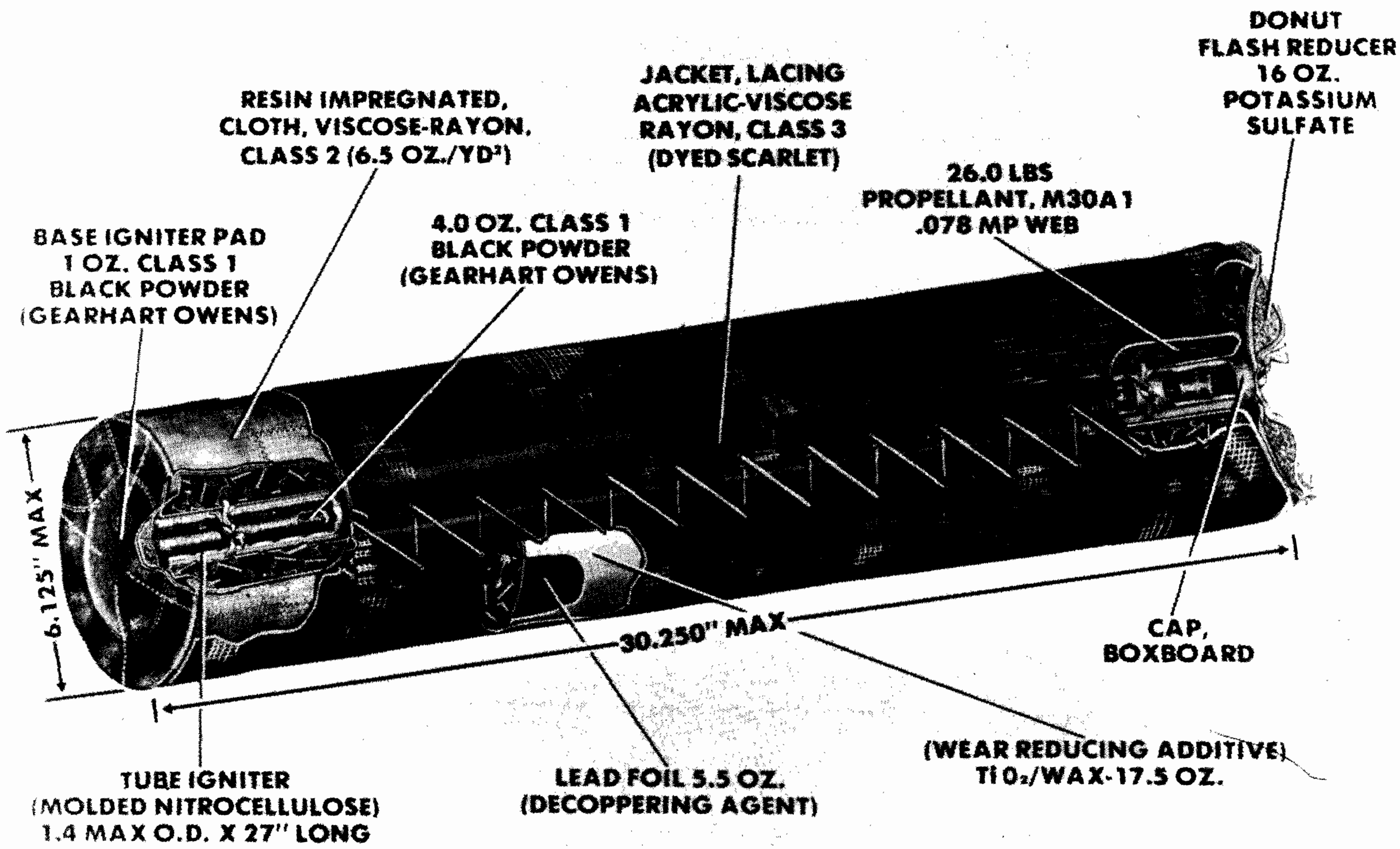

Figure 3. 155-mm, M203 Propelling Charge

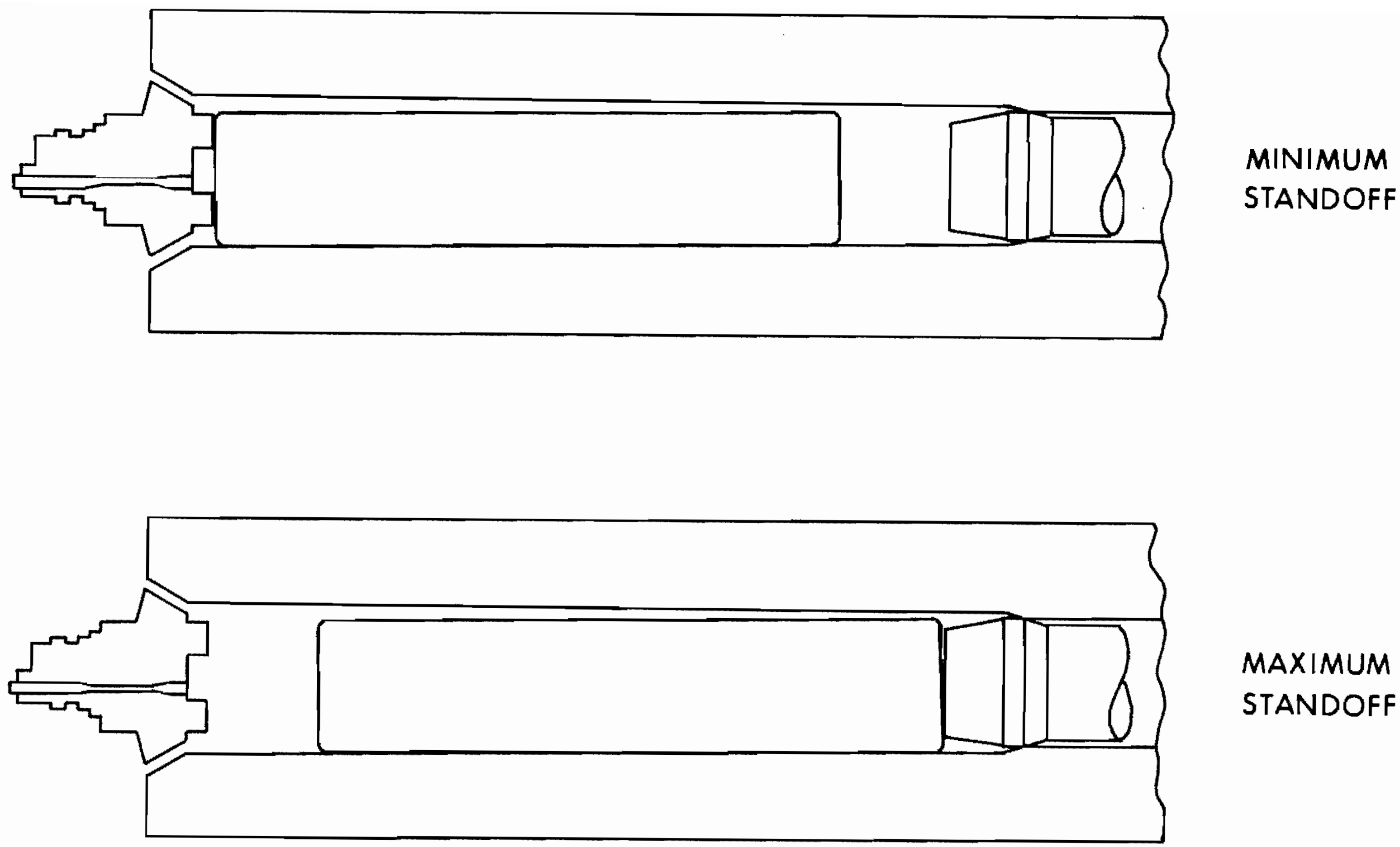

Figure 4. Extreme Loading Configurations for M203E1 Charge in M198 Howitzer

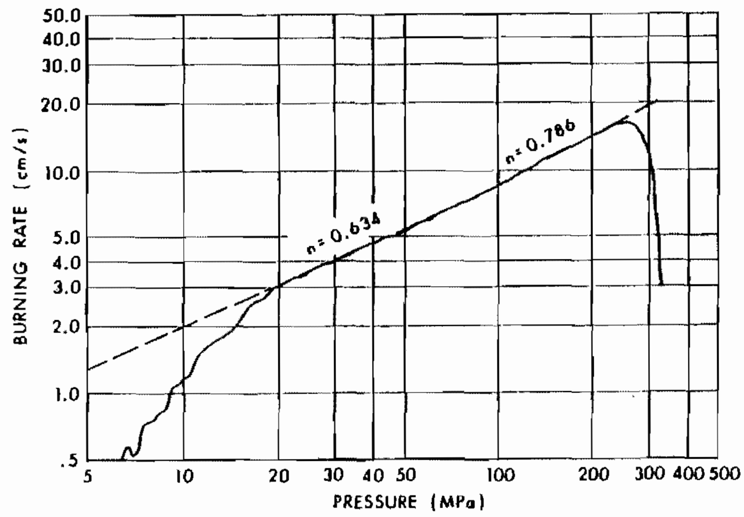

Figure 5. Closed Bomb Results for M30A1 Propellant

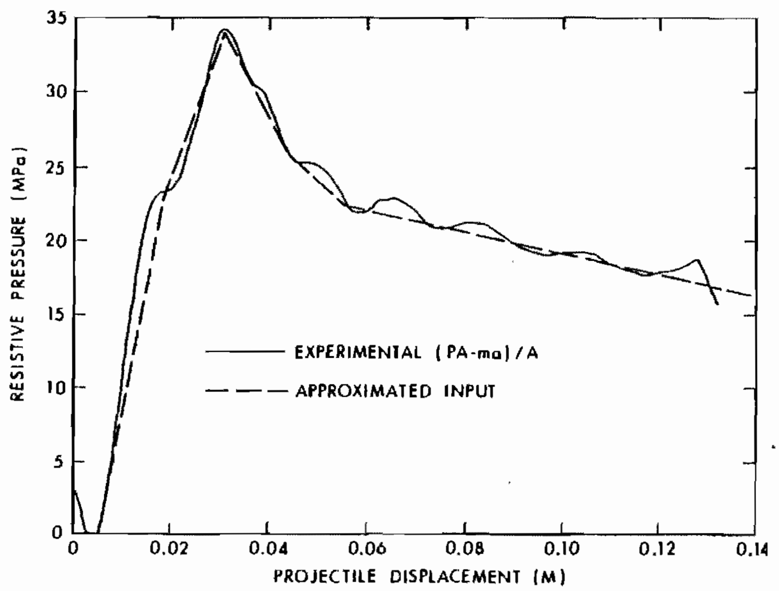

Figure 6. Experimental Bore Resistance Profile
(Zone 8 Charge, M101 Projectile)

IV. RESULTS AND DISCUSSION

We comment first on the fact that while experimentally observed muzzle velocities and, to a lesser degree, maximum chamber pressures are usually quite reproducible, the presence of longitudinal pressure waves may pass all but unnoticed or be quite pronounced. Figures 7 and 8 present pressure-time data recorded during firings of the M203E1 Charge, properly loaded in the gun chamber with the basepad approximately 25 mm from the spindle face. This standoff distance is assured in the M199 Cannon by the presence of 25.4-mm bumps on the spindle face. The smooth pressurization profiles of Figure 7 may be associated with proper and prompt initiation of the centercore black powder charge, which in turn ignites the main propellant charge over a distributed longitudinal region in an effectively simultaneous time frame. On the other hand, late initiation of the centercore, perhaps resulting from misalignment between the spindle spithole and the centercore itself, might lead to direct ignition transfer from the basepad to the main propellant charge - a more localized ignition, favoring the formation of pressure waves. It is also important to note that ignition delays for ambient ($\sim$21°C) firings usually fall in the 50-100 ms range, a figure an order of magnitude higher than that typically exhibited by cased charges employing high-pressure bayonet primers.

A NOVA code simulation of this charge/cannon configuration, using the input data base described in the previous section and listed in the Appendix, provided the results depicted in Figure 9. Overall pressurization profiles are quite similar to the experimental data. In fact, considering the use of a completely independent input data base, the agreement might be termed remarkable, though perhaps fortuitous.

Detailed analysis of a comparison of predicted and observed pressure-difference profiles, however, reveals some disturbing features (see Figure 10). First, we notice a strong, predicted positive difference (i.e., local pressurization at the breech end of the chamber) not observed experimentally. This prediction may be a consequence of the one-dimensional approximation, which requires that all basepad combustion products pass into the low permeability propellant bed, as opposed to venting around the charge external to the bag, rapidly equilibrating pressures throughout the chamber. The schematic representations of Figure 11 serve to clarify this point. This same configural difference between NOVA and reality may also be responsible, in part, for the predicted, short ignition delays ($\sim$5 ms). Additional major contributors to the real-world delay ($\sim$60 ms) may be the bag and associated parasitic components themselves. As a result of the predicted, rapid ignition at the rear of the main charge, input data reflecting functioning of the igniter centercore are of no consequence, as they represent igniter output after flamespread throughout the bed has been calculated to be complete. Hence, NOVA predicts a monotonic propagation of flame forward through the bed, accompanied by a strong stagnation at the projectile base (indicated in Figure 10 by an initial reverse pressure difference of $\sim$ - 20 MPa). However, the resulting longitudinal pressure wave is

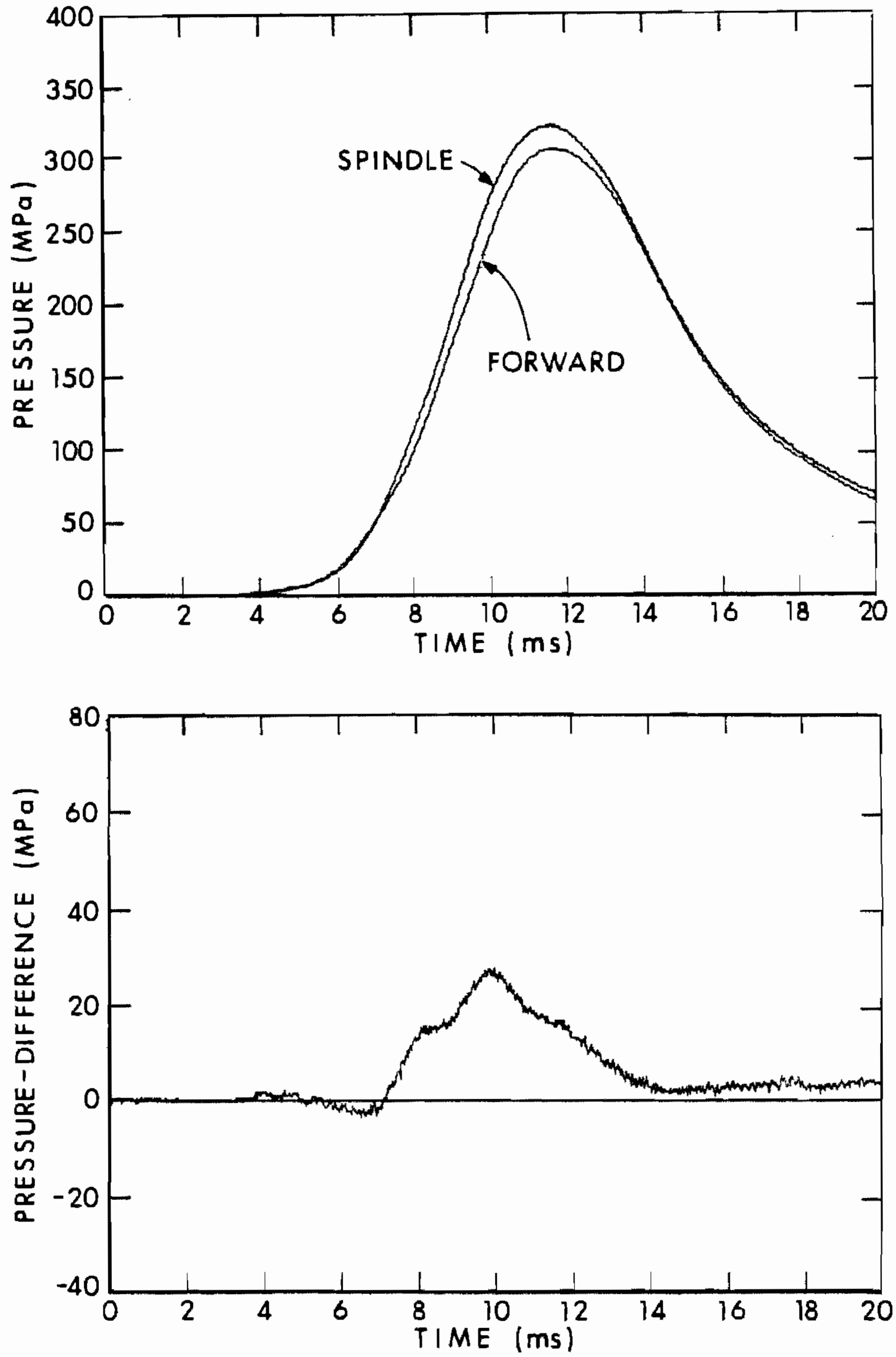

Figure 7. Typical Experimental Pressurization Profiles: M203E1 Propelling Charge, 25-mm Standoff (Arbitrary Zero Time)

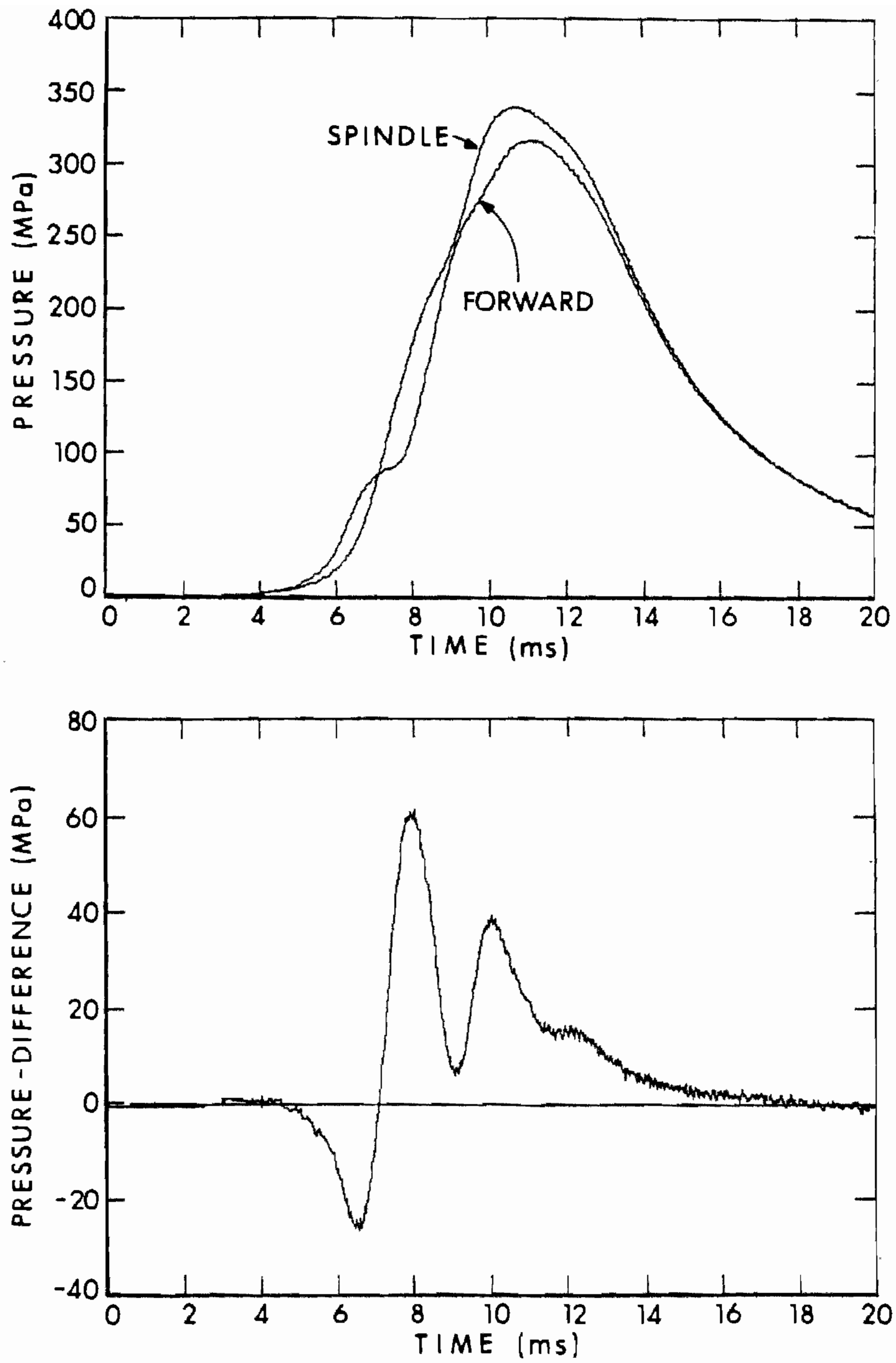

Figure 8. Experimental Pressurization Profiles Exhibiting Waves: M203E1 Propelling Charge, 25-mm Standoff (Arbitrary Zero Time)

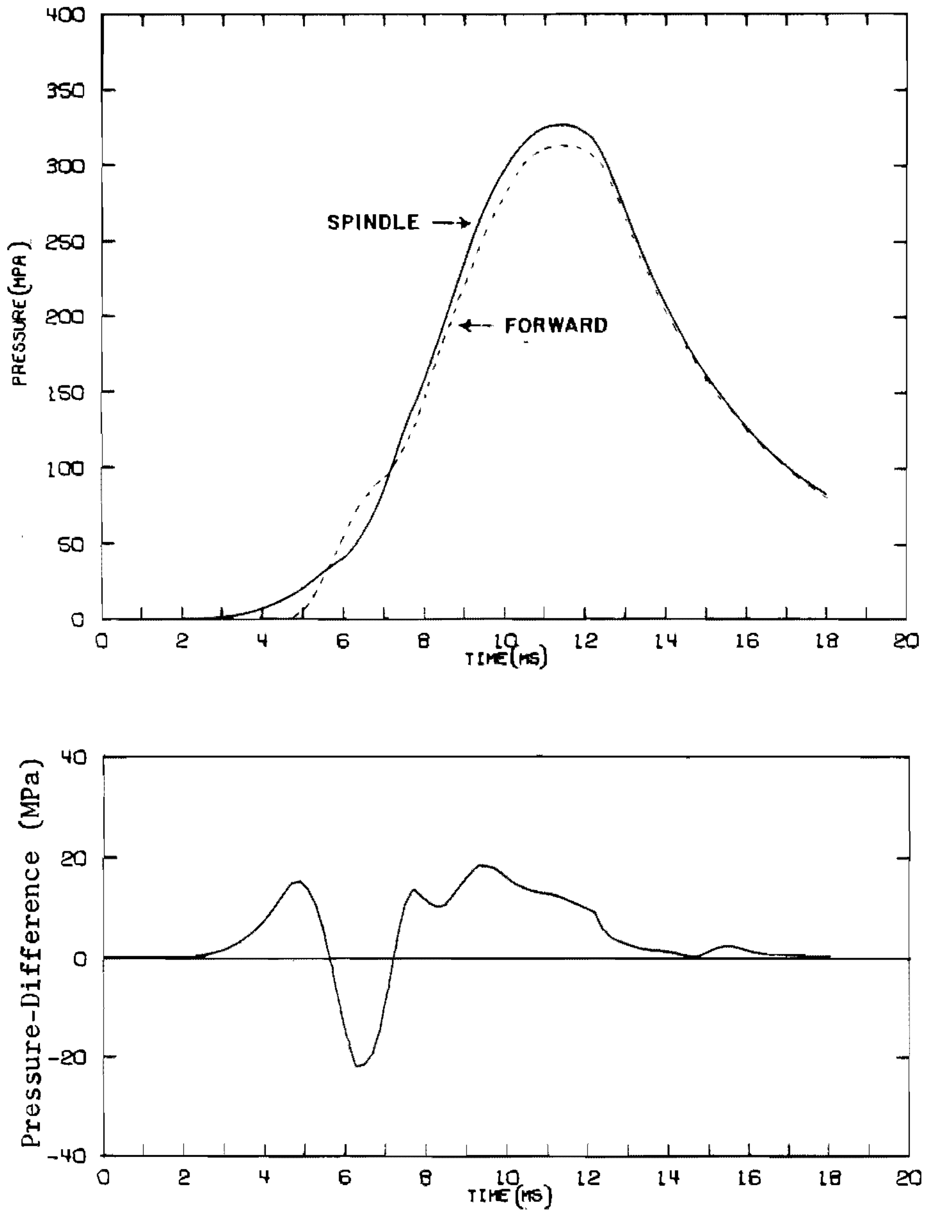

Figure 9. NOVA Simulation: M203E1 Propelling Charge, 25-mm Standoff

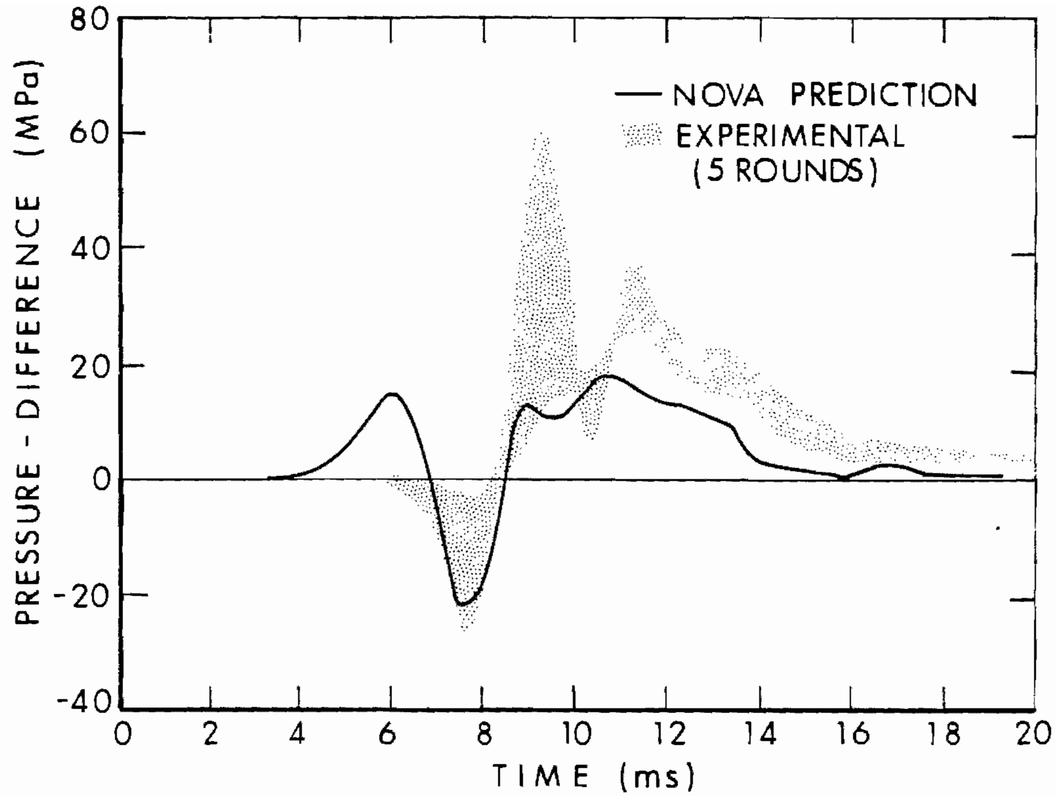

Figure 10. Comparison of Predicted and Experimental Pressure-Difference Profiles: M203E1 Propelling Charge, 25-mm Standoff

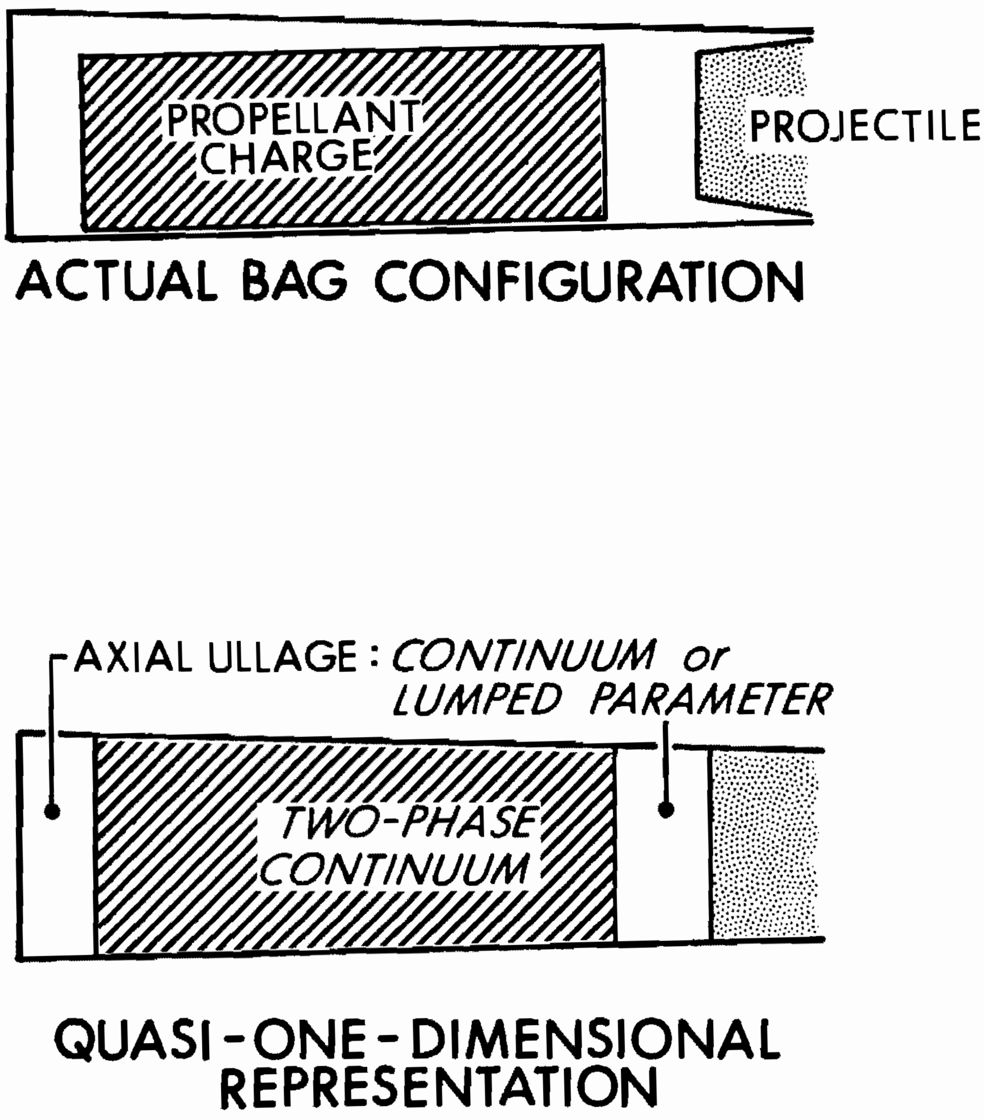

Figure 11. Schematic Representations of Bagged-Charge Configuration

predicted to decrease rapidly in amplitude. The experimental curve exhibiting a similar initial reverse pressure-difference level (shown separately in Figure 8) does not reveal the same characteristic damping rate. This discrepancy may reflect some inadequacy of the interphase drag law included in NOVA, coupled perhaps with a misrepresentation of propellant bed rheology - neither element of constitutive physics being adequately supported by experimental data.

As mentioned previously, a NOVA calculation was also performed to simulate the loading condition whereby the propelling charge is pushed all the way forward against the projectile base. With the M483A1 Projectile and the M203E1 Propelling Charge, this configuration may result in as much as 150 mm between the spindle face and the base of the charge. With the exception of this initial positioning of the charge, input data remained the same as presented in the Appendix. Figure 12 presents pressurization profiles resulting from this calculation. An increased level of longitudinal pressure waves is indicated. A comparison of this predicted pressure-difference profile to a band of maximum-standoff, firing data is shown in Figure 13. We see excellent qualitative and fairly good quantitative agreement between theory and experiment. As before, the predicted pressure waves tend to dampen out more rapidly than is indicated by the firing data. Of more concern, however, is the continued disparity between NOVA and reality prior to completion of flamespread and the initial stagnation at the projectile base. We still observe an order of magnitude difference in ignition delays between experiment and theory (not obvious in the figures because zero reference times were shifted when presenting experimental data).

The one-dimensional approximation does appear, however, to have provided a much more satisfactory simulation of the maximum charge standoff configuration than of the nominal 25-mm condition. This improvement may result chiefly from an increased likelihood of largely base ignition of the main charge at maximum standoff, as a consequence of the poorer interface between the primer spithole and the igniter centercore charge. Coupled with a slight reduction in annular ullage external to the charge (because of the tapered gun chamber) and elimination of the forward reservoir of ullage, this mode of ignition may lead to a nearly one-dimensional process (at least on the macroscopic level), more successfully represented in NOVA.

V. CONCLUDING REMARKS

A NOVA simulation of a 155-mm, M198 Howitzer, employing an M203E1 (Zone 8) Propelling Charge and described by an independently acquired data base (including propellant burning rates and projectile engraving friction/bore resistance), led to a surprisingly good simulation of gross interior ballistic parameters. However, a more detailed analysis of accompanying two-phase flow phenomena for normal loading (25-mm standoff) of the charge revealed a failure to accurately simulate experienced ignition delays and subsequent pressure-wave characteristics.

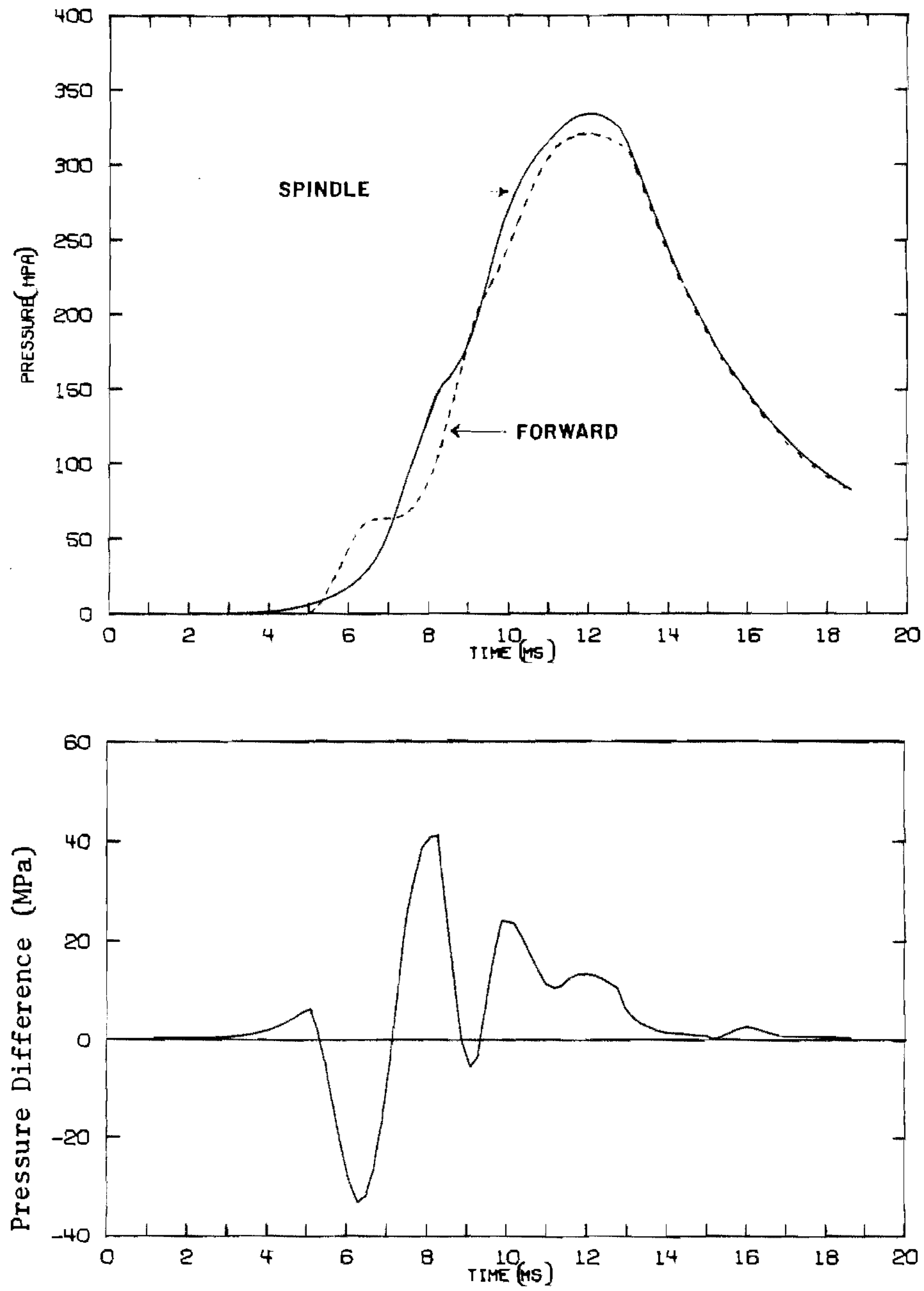

Figure 12. NOVA Simulation: M203E1
Propelling Charge, Maximum Standoff

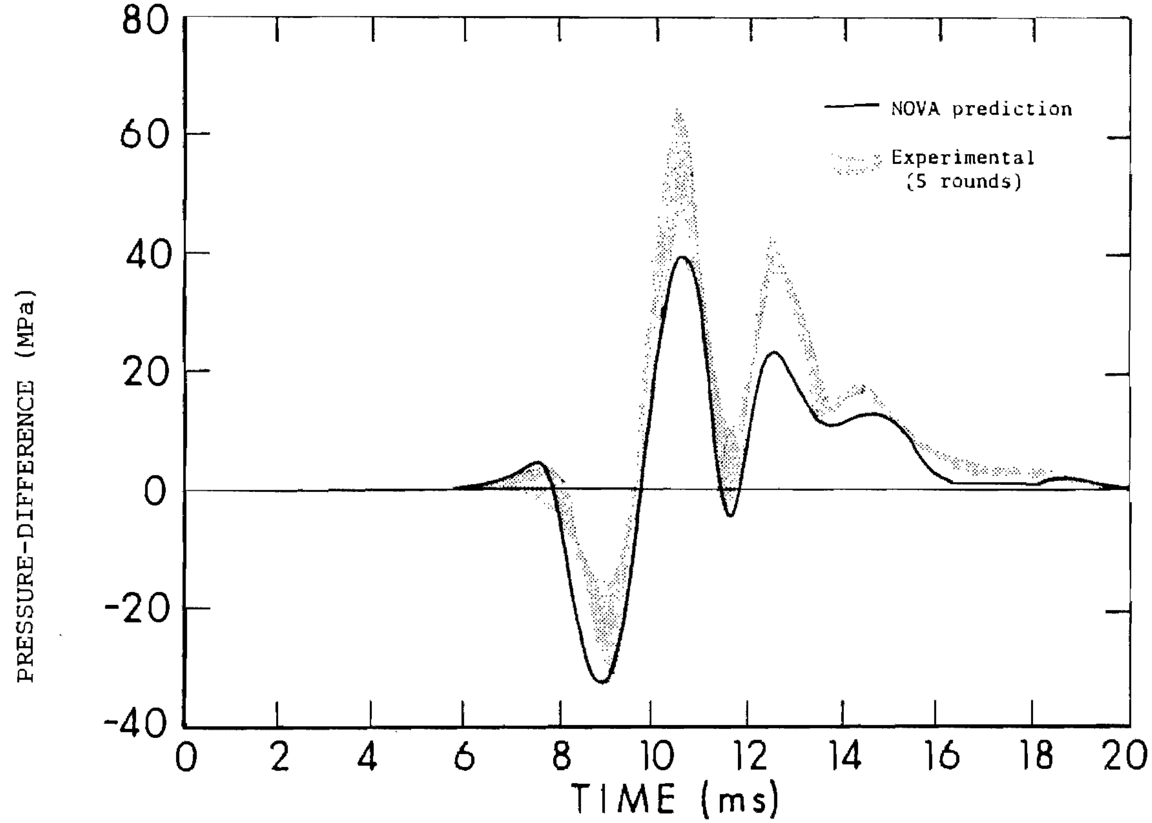

Figure 13. Comparison of Predicted and Experimental Pressure-Difference Profiles: M203E1 Propelling Charge, Maximum Standoff

An attempt to simulate the same system with maximum allowable charge standoff ($\sim$ 150mm) led to improved agreement between theory and experiment with respect to pressure waves, particularly as depicted by the pressure-difference profile, but not to ignition delays. Once combustion at the base of the charge commences, however, the remainder of the prediction compares quite favorably with previous NOVA successes in simulating cased charges. Better simulation of the maximum standoff configuration may well be the result of bringing reality more into line with the one-dimensional view of life to which NOVA is presently constrained.

Two-dimensional and, perhaps to a somewhat lesser degree, quasi-two-dimensional[18] representations should greatly facilitate modeling of bagged charges, particularly when centercore ignition dominates. Before any significant gains can be realized from a multi-dimensional representation, however, such features of the charge as bag cloth rupture strength and parasitic component properties may have to be investigated and incorporated into the code. Accurate simulation of ignition delays experienced with low-pressure ignition systems may also require incorporation of a more realistic criterion for propellant ignition, as well as recognition of a more complicated sequence of events involved in the transition to full combustion. The adequacy of the current surface temperature criterion, at least for application to modeling of flamespread and pressure waves, associated with bagged charges will be more appropriately investigated within the framework of multi-dimensional codes now under development.

[18] *P. S. Gough, "Theoretical Study of Two-Phase Flow Associated with Granular Bag Charges," USA ARRADCOM, USA Ballistic Research Laboratory Contract Report No. 00381, Aberdeen Proving Ground, MD, September 1978.* (AD #A062144)

REFERENCES

1. C.W. Nelson, "Some Simulations of a 155mm Howitzer with the NOVAE Code," USA ARRADCOM, USA Ballistic Research Laboratories Interim Memorandum Report No. 451, Aberdeen Proving Ground, MD, November 1975. (No longer available.)

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17. E.V. Clarke, Jr., USA Ballistic Research Laboratory, Personal Communication, Aberdeen Proving Ground, MD, October 1978.

18. P.S. Gough, "Theoretical Study of Two-Phase Flow Associated with Granular Bag Charges," USA ARRADCOM, USA Ballistic Research Laboratory Contract Report No. 00381, Aberdeen Proving Ground, MD, September 1978.

APPENDIX

LISTING OF INPUT DATA

155MM M203E1 CHARGE M199 CANNON M483A1 PRCJ (HORST025)

CONTROL DATA

```
LOGICAL VARIABLES:
PRINT 1      GRAPH 0      DISK WRITE 0      DISK READ 0
I.B. TABLE 1      FLAME TABLE 1      PRESSURE TABLE(S) 1
EROSIVE EFFECT 0      DYNAMIC EFFECT 0      WALL TEMPERATURE CALCULATION 0
LEFT HAND BOUNDARY CONDITION 0      RIGHT HAND BOUNDARY CONDITION 0      LEFT HAND RESERVOIR 0
RIGHT HAND RESERVOIR 0      BED PRECOMPRESSED 0
HEAT LOSS CALCULATION 0      INSULATING LAYER 0

BORE RESISTANCE FUNCTION 1
```

INTEGRATION PARAMETERS

NUMBER OF STATIONS AT WHICH DATA ARE STORED	35
NUMBER OF STEPS BEFORE LOGOUT	50
TIME STEP FOR DISK START	0
NUMBER OF STEPS FOR TERMINATION	2500
TIME FOR TERMINATION (SEC)	.2000E-01
PROJECTILE TRAVEL FOR TERMINATION (INS)	205.00
MAXIMUM TIME STEP (SEC)	.1000E-03
STABILITY SAFETY FACTOR	2.00
SOURCE STABILITY FACTOR	.0500
SPATIAL RESOLUTION FACTOR	.0100
TIME INTERVAL FOR I.B. TABLE STORAGE(SEC)	.2000E-03
TIME INTERVAL FOR PRESSURE TABLE STORAGE (SEC)	.1000E-03

FILE COUNTERS

NUMBER OF STATIONS TO SPECIFY TUBE RADIUS	3		
NUMBER OF TIMES TO SPECIFY PRIMER DISCHARGE	8		
NUMBER OF POSITIONS TO SPECIFY PRIMER DISCHARGE	5		
NUMBER OF ENTRIES IN BORE RESISTANCE TABLE	7		
NUMBER OF ENTRIES IN WALL TEMPERATURE TABLE	0		
NUMBER OF ENTRIES IN FILLER ELEMENT TABLE	0		
NUMBER OF TYPES OF PROPELLANTS	1		
NUMBER OF BURN RATE DATA SETS	2		
NUMBER OF ENTRIES IN VOID FRACTION TABLE(S)	0	0	0
NUMBER OF ENTRIES IN PRESSURE HISTORY TABLES	3		
NUMBER OF ENTRIES IN LEFT BOUNDARY SOURCE TABLE	0		
NUMBER OF ENTRIES IN RIGHT BOUNDARY SOURCE TABLE	0		
NUMBER OF WALL STATIONS FOR INVARIANT EMBEDDING	0		
NUMBER OF BED STATIONS FOR INVARIANT EMBEDDING	0		
FRICTION COEFFICIENT	1.0		

GENERAL PROPERTIES OF INITIAL AMBIENT GAS

INITIAL TEMPERATURE (DEG.R)	530.0
INITIAL PRESSURE (PSI)	14.7
MOLECULAR WEIGHT (LBM/LBMOL)	29.000
RATIO OF SPECIFIC HEATS	1.4000

GENERAL PROPERTIES OF PROPELLANT BED

INITIAL TEMPERATURE (DEG.R)	530.0		
VIRTUAL MASS CONSTANT (-)	0.000		
VOID FRACTION PACKING COEFFICIENTS	0.0000	0.0000	0.0000

PROPERTIES OF PROPELLANT 1

PROPELLANT TYPE	M30A1,RAD-E-069805
MASS OF PROPELLANT (LBM)	26.1500
DENSITY OF PROPELLANT (LBM/IN**3)	.0572
FORM FUNCTION INDICATOR	7
OUTSIDE DIAMETER (INS)	.4173
INSIDE DIAMETER (INS)	.0338
LENGTH (INS)	.9481
NUMBER OF PERFORATIONS	7.

RHEOLOGICAL PROPERTIES

SPEED OF COMPRESSION WAVE IN SETTLED BED (IN/SEC)	17400.
SETTLING POROSITY	.4243
SPEED OF EXPANSION WAVE (IN/SEC)	50000.

SOLID PHASE THERMOCHEMISTRY

MAXIMUM PRESSURE FOR BURN RATE DATA (LBF/IN**2)	10000.
BURNING RATE PRE-EXPONENTIAL FACTOR (IN/SEC/PSI**BN)	.6918E-02
BURNING RATE EXPONENT	.6337
MAXIMUM PRESSURE FOR BURN RATE DATA (LBF/IN**2)	60000.
BURNING RATE PRE-EXPONENTIAL FACTOR (IN/SEC/PSI**BN)	.1743E-02
BURNING RATE EXPONENT	.7864
BURNING RATE CONSTANT (IN/SEC)	0.0000
IGNITION TEMPERATURE (DEG.R)	810.0
ARRHENIUS ACTIVATION ENERGY (LBF-IN/LBMOL)	0.
FREQUENCY FACTOR (SEC**-1)	0.
THERMAL CONDUCTIVITY (LBF/SEC/DEG.R)	.2770E-01
THERMAL DIFFUSIVITY (IN**2/SEC)	.1345E-03
EMISSIVITY FACTOR	.600

GAS PHASE THERMOCHEMISTRY

CHEMICAL ENERGY RELEASED IN BURNING(LBF-IN/LBM)	.17600E+08
MOLECULAR WEIGHT (LBM/LBMOL)	23.3600
RATIO OF SPECIFIC HEATS	1.2430
COVOLUME	28.5000

LOCATION OF PACKAGE(S)

PACKAGE	LEFT BODY(INS)	RIGHT BODY(INS)	MASS(LBM)
1	1.000	30.000	26.150

PROPERTIES OF PRIMER

CHEMICAL ENERGY RELEASED IN BURNING(LBF-IN/LBM)	.6303E+07
MOLECULAR WEIGHT (LBM/LBMOL)	36.1300
RATIO OF SPECIFIC HEATS	1.2500
SPECIFIC VOLUME OF SOLID(IN**3/LBM)	15.3850

PRIMER DISCHARGE FUNCTION (LBM/IN/SEC)

POS.(INS) TIME(SEC)	0.00	1.00	1.01	30.00	31.00
0.	6.00	6.00	0.00	0.00	0.00
.100E-01	6.00	6.00	0.00	0.00	0.00
.110E-01	0.00	0.00	0.00	0.00	0.00
.490E-01	0.00	0.00	0.00	0.00	0.00
.500E-01	0.00	1.00	1.00	1.00	0.00
.600E-01	0.00	1.00	1.00	1.00	0.00
.610E-01	0.00	0.00	0.00	0.00	0.00
.100E+00	0.00	0.00	0.00	0.00	0.00

PARAMETERS TO SPECIFY TUBE GEOMETRY

DISTANCE(IN)	RADIUS(IN)
0.000	3.610
32.340	3.080
235.300	3.080

BORE RESISTANCE TABLE

POSITION(INS)	RESISTANCE(PSI)
35.000	250.
35.400	3350.
36.000	4950.
36.550	3625.
37.050	3250.
39.500	2500.
240.000	1500.

THERMAL PROPERTIES OF TUBE

THERMAL CONDUCTIVITY (LBF/SEC/DEG.R)	7.770
THERMAL DIFFUSIVITY (IN**2/SEC)	.2280E-01
EMISSIVITY FACTOR	.700
INITIAL TEMPERATURE (DEG.R)	530.00

PROJECTILE AND RIFLING DATA

INITIAL POSITION OF BASE OF PROJECTILE(INS)	35.000
MASS OF PROJECTILE (LBM)	103.000
POLAR MOMENT OF INERTIA (LBM-IN**2)	14.000
ANGLE OF RIFLING (DEG)	6.000

POSITIONS FOR PRESSURE TABLE STORAGE

0.0000	16.0000	32.0000

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